The vegetation of Singapore —an updated map

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ABSTRACT. The primeval vegetation of Singapore was largely lowland dipterocarp forest, with mangrove forest lining much of the coast and freshwater swamp forest found further inland adjacent to the streams and rivers. After colonization by the British in 1819, almost all the primeval vegetation was cleared for agriculture and other land uses. The most comprehensive vegetation map of Singapore was made in the 1970s and has not been updated since. Here we present an updated vegetation map of Singapore using information from satellite images, published works, and extensive ground-truthing. Vegetation covers 56% of Singapore's total land area: 27% is actively managed (parks, gardens, lawns, etc.) and 29% is spontaneous vegetation. Primary lowland dipterocarp forest and freshwater swamp forest cover only 0.28% and is confined to the Bukit Timah and Central Catchment Nature Reserves. The majority of the non-managed vegetation is secondary forest of various kinds, dominated by native or alien trees. The managed vegetation and alien-dominated secondary vegetation are understudied and deserve more research attention. The vegetation of Singapore should be re-mapped at regular intervals in order to better understand the changes.

Keywords. Forest, map, Singapore, vegetation

Introduction

Most of primeval Singapore was covered by forest, while open habitats were largely confined to beaches and coastal cliffs (Corlett 1991, 1992a). According to Corlett (1991), 13% of the primeval vegetation was mangrove forest, 5% was freshwater swamp forest, and the rest was mainly lowland dipterocarp forest (Fig. 1). Although the island had been continuously inhabited for several centuries, rapid deforestation occurred only after colonization by the British in 1819. By 1900, 90% of the primeval forest had been cleared, mainly for agriculture and by 1935, rubber plantations occupied 40% of Singapore's area (Corlett 1991).

After the independence of Singapore in 1959, land use change was driven by urbanization and modernization. Active large-scale land reclamation has been carried out since the 1960s (Wong 1985). By 1973, less than 30% of Singapore's land area was covered by spontaneous vegetation while the rest was plantations, and suburban and

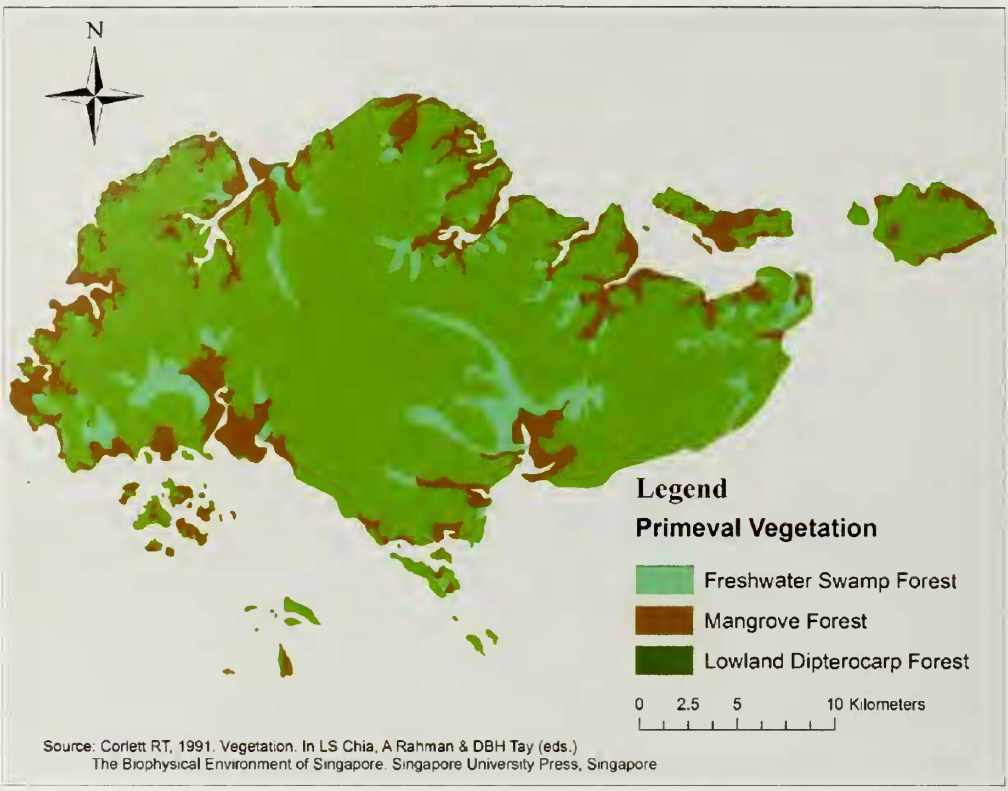

Fig. 1. Vegetation map of primeval Singapore.

urban areas (Hill 1977). By 1990, more than half of Singapore was urbanized, most of the plantations were abandoned and more than 99% of the original forest had been cleared (Corlett 1991, 1992a).

The vegetation of Singapore was partly mapped in the nineteenth century. For example, Coleman's and Thomson's maps showed vegetation around the Singapore Town (see Corlett 1992b). Vegetation can also be inferred from the topographic maps of Singapore. R.D. Hill (1977) produced the first extensive vegetation map based on aerial photographs from 1959 and 1969, and ground truthing from 1972 to 1973. Subsequently, only maps of specific areas or vegetation types were produced, such as the mangrove vegetation map of Hilton & Manning (1995), and the map of the vegetation of the Bukit Timah and Central Catchment Nature Reserves (see Corlett 1997). Therefore, we aim to produce a recent vegetation map for the entire Singapore.

Materials and methods

Ground truthing was carried out in Singapore from June 2009 to March 2010. The vegetation types were noted down in Singapore Street Directory, 2009 edition (Mighty Minds® 2009) if the area was bounded by roads, or in a GPS receiver (Garmin

GPSMAP® 60CSx) with at most ±7 m error if it was not bounded by roads. From the ground truthing data, 405 regions of interest (ROIs) were created.

Two SPOT 5 satellite images from 08 Mar. 2006 and 31 Aug. 2007, and the 405 ROIs were used to create a vegetation map of Singapore by a supervised classification technique, using the maximum likelihood method, which is available in the software package ENVI version 4.4 (ITT Visual Information Solution 2007). A total of 85 out of the 405 ROIs were used as the training data. The remaining 320 ROIs were used to assess the accuracy of the supervised classified vegetation map via the 'confusion matrix' function in ENVI version 4.4. Both satellite images underwent the same procedures. We adopted the standard of Thomson et al. (1999), which suggested at least 85% for overall accuracy, and at least 70% accuracy for individual classes.

When desirable accuracy was obtained (Tables 1 & 2), the supervised classified vegetation map based on the 31 Aug. 2007 satellite image was overlain with that based on the 08 Mar. 2006 satellite image (Fig. 2). Subsequently, persisting clouded areas were filled in using information from Google Earth 5.1.3533.1731 (Google Inc. 2009).

Table 1. Confusion matrix computed for the automated vegetation map of year 2006. Values are reported in percentages. The overall accuracy is 86.30%, and the Kappa coefficient is 0.7907.

	Ground truthed				
Supervised classification	Water	Non-vegetated	Grassland	Forest	Mangrove forest
Water	92.73	3.32	0.38	0.59	3.42
Non-vegetated	5.10	80.04	9.14	3.41	4.08
Grassland	0.12	12.49	75.28	6.81	0.02
Forest	1.82	3.63	15.15	88.33	11.15
Mangrove Forest	0.23	0.52	0.05	0.87	81.33

Table 2. Confusion matrix computed for the automated vegetation map of 2007. Values are reported in percentages. The overall accuracy is 90.61%, and the Kappa coefficient is 0.8621.

	Ground truthed				
Supervised classification	Water	Non-vegetated	Grassland	Forest	Mangrove forest
Water	97.43	0.08	0.08	0.00	1.60
Non-vegetated	2.40	88.09	7.99	0.59	3.08
Grassland	0.00	9.81	74.94	5.84	0.07
Forest	0.00	1.68	16.53	93.13	8.84
Mangrove Forest	0.17	0.35	0.46	0.45	86.41

Fig. 2. The final automated vegetation map of Singapore produced by filling in the clouded areas of the 2007 map with patches from the 2006 map.

The map was then overlain with layers showing the managed area in Singapore, and the Singapore Greenery Map (see Tee et al. 2009). Lastly, it was overlain with a layer showing areas of primary forest, old secondary forest, freshwater swamp forest, and mangrove forest, using information from personal communications and observations, the topographic map of Singapore (Singapore Mapping Unit 2006), the vegetation of the Bukit Timah and Central Catchment Nature Reserves (Corlett 1997), map of the freshwater swamp at Nee Soon (Tuner et al. 2006), and the mangrove vegetation of Singapore (Yee et al. 2010). As intermediate vegetation types exist, especially between young and old secondary forests, this study adopted a more conservative approach in classifying such vegetation. Hence, for example, forest that was intermediate between young and old secondary forest would be classified as young secondary forest.

Results and Discussion

Table 3 lists the spatial extent of each vegetation class and the updated vegetation map of Singapore is shown in Fig. 3. Vegetation covers 56% of Singapore's total land area. Actively managed vegetation occupies 27% of the total landmass while 29% of the area is covered by spontaneous vegetation, which includes scrubland, lowland forest, freshwater swamp forest, freshwater marsh, and mangrove forest. Primary forest only

Table 3. Area, proportion, and number of patches for each vegetation type. The total land area of Singapore taken here is 72,574.68 ha.

Vegetation types	Area (ha)	Proportion (%)	Number of patches
Non-vegetated	28,270.43	38.85	22275
Managed vegetation	19,972.96	27.45	29075
Scrubland	4,307.54	5.92	8340
Young secondary Forest	14,288.48	19.64	2920
Old secondary forest	994.68	1.37	42
Primary lowland dipterocarp forest	118.34	0.16	15
Mangrove forest	662.43	0.91	491
Freshwater marsh	76.6	0.11	227
Freshwater swamp forest	283.12	0.39	125

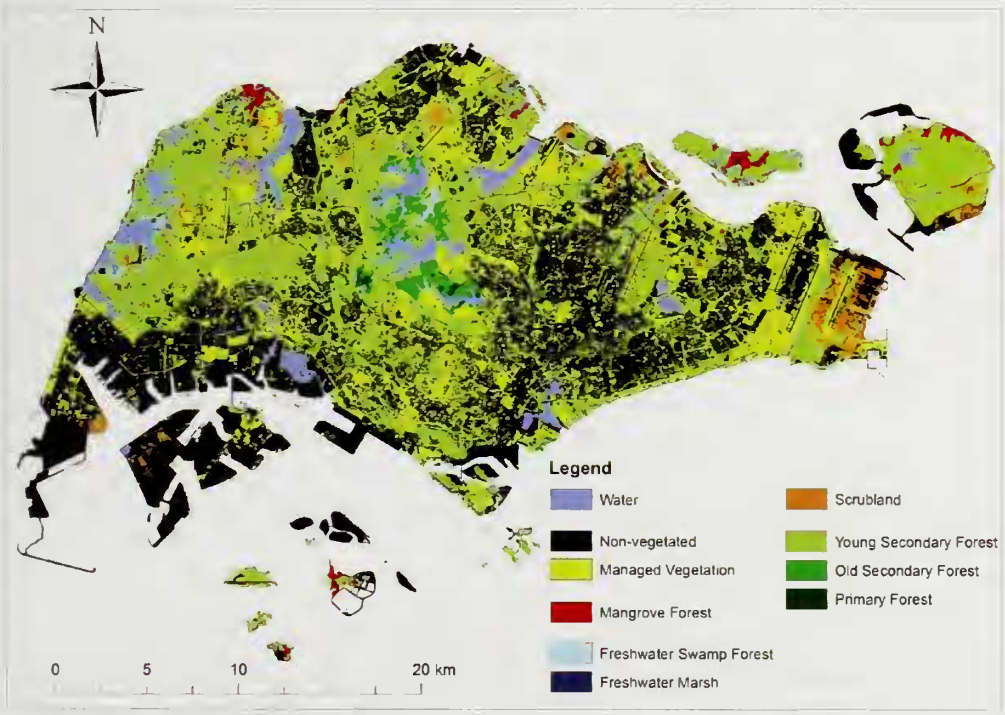

Fig. 3. The manually edited vegetation map of Singapore.

occupies 0.28% of Singapore's total landmass. A total of 118 ha of primary lowland dipterocarp forest can be found in the Bukit Timah Nature Reserve and in patches scattered throughout the Central Catchment Nature Reserve. Primary freshwater swamp forest, which is estimated to be 87 ha, can only be found in the Nee Soon swamp forest, which is located in the Central Catchment Nature Reserve (Turner et al. 1996).

Most of the spontaneous vegetation in Singapore belongs to lowland young secondary forest. The lowland young secondary forest can be further subdivided into native-dominated forest [e.g., young secondary forest dominated by *Adinandra dumosa* (Holttum 1954; Sim et al. 1992)], abandoned plantations, and open woodlands. However, these subtypes are not reflected in the map because they could only be poorly separated in the satellite images used. Moreover, extensive ground truthing in this forest type was not possible as some areas are inaccessible. Nonetheless, we observed that open woodlands, which are usually dominated by exotics like *Acacia auriculiformis* and *Leucaena leucocephala,* are common in recently cleared or reclaimed land. In the Nature Reserves in the centre of the island, native-dominated young secondary forests have been replaced through forest succession by taller, more species-rich, native-dominated old secondary forests (Corlett 1997), but the eventual fate of the exotic-dominated secondary forests outside the Reserves is unclear.

The ecology of managed vegetation in Singapore is also not well-understood, despite it constituting 48% of the total vegetation cover. As the major land use type in Singapore, managed vegetation has significant conservation potential and it has received increasing attention from the Singapore government lately. The planted trees can provide foods for birds and mammals. For example, the common palm civet (*Paradoxurus hermaphroditus*) has been found to feed on fruits of the rain tree (*Albizia saman*), the most widely planted street tree in Singapore (Xu 2010).

There are some limitations with the map. Firstly, it is based on satellite images from the years 2006 and 2007, but ground truthing was carried out in 2009 and 2010. This is likely to have affected the regions-of-interest (ROIs) drawn, hence affecting the supervised classification, and the accuracy of the map. Secondly, the maximum likelihood produces a hard (all or nothing) classification, assuming the whole pixel is homogenous. In reality pixels are rarely homogenous: for example, a pixel classified as forest might actually not be fully forested. Lastly, intermediate vegetation types exist, and this would once again affect the ROIs drawn. Despite these caveats, this map is still a good approximation to the vegetation of Singapore in 2006–2010. Fine-tuning could be done by using higher resolution satellite images and more ground truthing. We recommend a long-term follow-up study to document the changes in the vegetation of Singapore.

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